Chapter 5. Streams and Riparian Areas

This summary of the best available science for developing policies and regulations to protect the functions and values of stream and associated riparian areas is based on peer-reviewed research; Bellevue's 2003 *Critical Areas Update, Stream Inventory Report;* Bellevue's 2003 *Critical Areas Update, Best Available Science Paper: Streams*; symposia literature; technical literature; and other scientific information related to streams. Best available science for stream and riparian protection varies in terms of quantity, quality, and local relevance. The best available science for stream and riparian protection is neither complete nor consistently covers all functions, and it remains an active field of research. The review focused on recommended conservation or protection measures to preserve or enhance anadromous fish species and habitat that is important for all life stages of anadromous fish.

In 2003, the City of Bellevue documented conditions of local streams in a report titled "*Bellevue Critical Areas Update Stream Inventory*" and also published a review of best available science for streams in a paper titled "*Bellevue Critical Areas Update Best Available Science Paper: Streams*". This report provides a peer review of these documents using current best available science sources for stream protection. It updates current knowledge and provides recommendations for policies to protect local streams.

This document incorporates a discussion of the aquatic area processes and functions not discussed in the 2003 best available science paper on streams. In addition, this document includes critical area protection recommendations to protect the functions and values of streams with special consideration given to conservation and enhance of anadromous fish species, particularly salmon. The stream protection issues reviewed include:

- Stream typing systems
- Stream buffers
- Piped stream buffers
- Structure setbacks
- Stewardship programs.

Relevant information was obtained from a variety of peer-reviewed sources meeting the criteria for best available science (WAC 365-195-900 to 925). Information was selected from scientific journals, published books, and government reports. Additional information from peer-reviewed research studies was included if performed by qualified researchers using documented scientific methods.

This report and findings should be used in conjunction with the 2003 *Bellevue Critical Areas Best Available Science: Streams Paper* (BAS Streams Paper) and the 2003 *Bellevue Critical Areas Update Stream Inventory Report* (Stream Inventory Report) to help provide information for policy recommendations for the management of streams and riparian areas in the City.

5.1 Functions and Values

The 2003 BAS Streams Paper specifically investigated stream processes and biological requirements of salmonids, salmon habitat needs, and the functions and values of riparian areas. While salmonids as well as many other aquatic organisms are confined to the stream aquatic environment, the various elements necessary for healthy salmonid and aquatic life populations do not rely solely on in-stream processes. Understanding how aquatic species and habitats are formed and sustained is essential in devising a strategy for their protection.

This section focuses on aquatic area processes and functions that should be considered when managing stream critical areas— with special consideration given to local core and satellite salmonids. Major paradigms of aquatic area processes not discussed in the 2003 report but addressed in this document include:

- The Role of Natural Disturbances
- River Continuum Concept
- Channel Migration Zone
- Hyporheic Zone.

Figure 5-1 illustrates the different zones affecting stream and riparian processes. Because of the unique mix of water and biodiversity, stream and riparian areas are used by a broad range of species including by humans for recreational and aesthetic activities, fishing, and the enjoyment of natural beauty and solitude.

5.1.1 The Role of Natural Disturbances

The interplay between water, soil, plants, and animals occurs in cycles of intensity driven by climatic and geological processes. Stochastic (random) processes and natural disturbances place stresses on the stream and associated riparian areas (stream corridor) and have the potential to reshape, rejuvenate, or impair its ability to perform ecological functions. Disturbances can occur anywhere within the stream corridor and can vary in terms of frequency, duration, and intensity. A single disturbance event may trigger a variety of disturbances that differ in frequency, duration, intensity, and location (NRC 1997). Ecologists (Holling 1973; White and Picket 1985) have long recognized the dynamic nature of aquatic and terrestrial ecosystems and how the associated biota and physical characteristics change through time due to stochastic processes and natural disturbances. Floods, fire, lightning, earthquakes, insects and disease, landslides, temperature extremes, and drought are among the many natural disturbances affecting structure and functions in the stream corridor (NRC 1997).

Natural disturbances can: (1) increase biological diversity; (2) be crucial for the persistence of some organisms and the habitat that supports them; and (3) express and maintain key ecological processes (Turner et al. 1994). The frequency and magnitude of disturbance events over time define the disturbance regime for an area. The disturbance regime largely defines the conditions in which native species adapt—plants and animals have evolved to cope with environmental perturbation (Reeves et al. 1995).

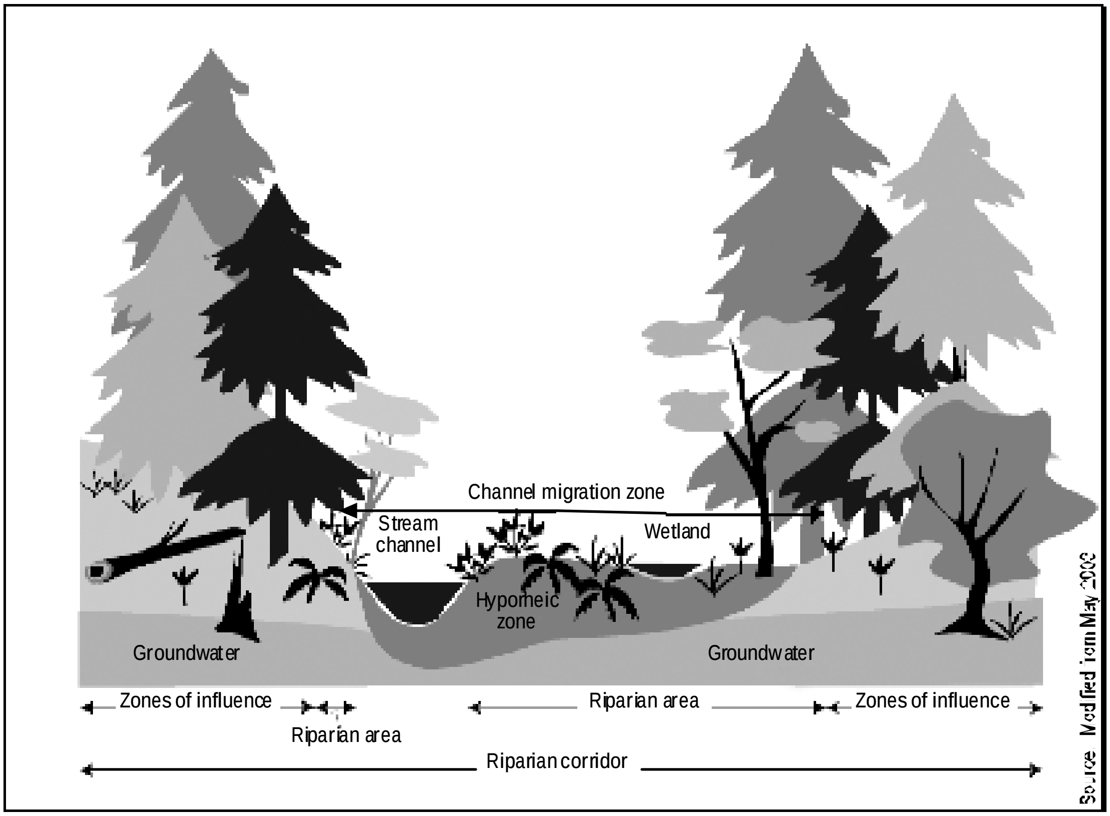

Figure 5-1. Typical stream and riparian zones.

Management efforts to suppress natural disturbances have often resulted in less biodiversity and ecosystem health (Averill et al. 1995); the literature refers to these actions as human-induced disturbance because they also stress the stream corridor and affect its ecological structure and function.

The majority of the degraded basin conditions in Bellevue are attributed to human-induced disturbances such as impervious surfaces, piped streams segments and urban encroachment into riparian areas (Bellevue 2003b). These human-induced disturbances affect the infiltration and movement of water and alter the structure of plant communities and soils—thereby alter riparian functions and values (Bellevue 2003a).

Natural disturbances increase biological diversity while human-induced disturbances decrease biological diversity (Averill et al. 1995); therefore, managers should strive to address human-induced disturbances through in stream corridor restoration. Flooding, drought, diseases, insects, and wind affect streamside areas located within Bellevue where streamside vegetation is present and streams are not piped. Habitat structure in the riparian area could be improved by allowing these potential disturbance processes to occur and, following the occurrence of disturbances, by not removing snags or downed trees but rather retaining them.

Metapopulations are groups of local populations that are distributed across a heterogeneous landscape and genetically linked by dispersal of individuals (Hanski 1991; Hanski and Gilpin 1991). Metapopulation theory directly links populations to the natural disturbance regimes that shape landscape structure and function. The linkage is the balance between the extinction of local populations after severe habitat disturbance and the subsequent recolonization of previously disturbed habitats as they recover. This extinction-colonization balance depends on the dispersal of individuals and the connectivity between habitats occupied by populations making up the metapopulation. If the frequency of disturbance that degrades a species' habitat exceeds its ability to maintain a balance between extinction and recolonization, the individual populations and eventually the entire metapopulation will go extinct (Opdam 1991).

Metapopulation theory has only recently been used to interpret salmonid population structure and ecology and to formulate management strategies (National Research Council 1996; Independent Scientific Group 1996). The core-satellite model describes the structure of Pacific salmon metapopulations (Li et al. 1995; Schlosser and Angermeier 1995; Independent Science Group 1996). Core populations are large, usually occupying extensive and productive habitats. Under natural conditions, core populations are expected to persist indefinitely. Core subareas are river and stream systems that are the primary spawning grounds for core population. Satellite subareas are marginal habitat occupied by satellite populations. The abundance of satellite populations may fluctuate widely in response to changes in climate, and they may go extinct after severe disturbance events. Salmon will disperse from a large core population and will colonize vacant habitat, reestablishing satellite populations and generally minimizing the possibility of total extinction of the metapopulation (Harrison 1994). Degraded habitat conditions in core subareas may lead to satellite populations supporting core populations. In this case, identifying and protecting all areas that support core populations and satellite populations is critical to prevent the extinction of the metapopulation and to ensure the possibility of recovery.

The Washington Conservation Commission (2001) identifies Kelsey Creek as a satellite subarea which supports local chinook core populations in the Greater Lake Washington Basin. Protecting and restoring habitat forming processes in Kelsey Creek is important to ensuring the survival of the Kelsey Creek satellite population and the core population of the Greater Lake Washington Basin.

5.1.2 The River Continuum Concept

Vannote et al. (1980) proposed the river continuum concept to describe freshwater habitat and the importance of various physical, chemical, and biological processes. According to the river continuum concept the distribution of stream characteristics reflects a headwater to mouth gradient of physical conditions that affect the biological components in a river including the location, type, and abundance of food resources with a given stream size. For example, the productivity of small streams is more dependent on riparian vegetation for their nutrients than larger streams which are dominated by primary production (Vannote et al. 1980). Overall the river continuum concept describes how the influence of riparian and landscape factors varies depending on stream size and how biological communities might change from headwater streams to larger rivers.

Vannote et al. (1980) also examined the role of aquatic areas along the river continuum that are fishless or isolated. Aquatic areas with no fish or potential for fish can occur in hydrologically connected waters or isolated waterbodies. In the case of small streams originating as spring seeps, water flows sometimes go underground before making a surface connection with a fish-bearing streams. In other situations there are lakes and ponds that have no surface connection to a fish-bearing stream or have waters that are unsuitable for fish (e.g., bogs that are too acidic). Regardless, isolated or otherwise fishless isolated waters can be used extensively by other animals, especially amphibians and macroinvertebrates for breeding, rearing, or refuge (Muchow and Richardson 2000). When these waters infiltrate below ground they contribute to the local aquifers that may ultimately supply fish-bearing waters with cool, clean ground water. Consequently fishless and isolated waters can function as habitat for non-fish species and indirectly provide for the water quality and hydrologic functioning of waters with fish.

In summary, the river continuum concept illustrates the importance of riparian vegetation for small streams and the functions and values of fishless aquatic areas. Within Bellevue the majority of the stream systems are small and several fishless areas are documented in the Stream Inventory Report. Small streams are highly dependent on organic matter deposited by the riparian forest, such as leaves, bark, and wood for nutrient inputs and therefore riparian vegetation along small streams should be maintained. Maintaining riparian vegetation around fishless aquatic areas is also vital to protect the function and values of these habitats for aquatic organisms, water quality and hydrologic functions.

5.1.3 Channel Migration Zone

The channel migration zone (CMZ) is the area where the active channel of a stream is prone to move laterally within the floodplain over time (May 2003). Fish and wildlife are dependent on the habitat created when a river is allowed to migrate. For example, gravel and vegetation that falls into rivers as they migrate create spawning areas and provide nutrients for salmonids. Usually, channel migration is a gradual process; however, it can occur abruptly through a process called avulsion (Dunne and Leopold, 1977). The primary ecological process that drives channel migration is flooding which delivers large volumes of water, sediment, and large woody debris (LWD). The process of flooding in an area has the potential to fill, create, or sustain stream habitat—the most commonly affected habitats during flooding are side channels and oxbow ponds.

Identification of CMZs requires site-specific analysis by qualified fluvial geomorphologists. However, in some instances, the CMZ can be roughly approximated by the 100-year flood zone as mapped by FEMA. The 100-year flood plains within the City of Bellevue have been mapped and are shown in Figure W-1 in the 2003 *Bellevue Critical Areas Update Wetland Inventory*. Kelsey Creek is the largest creek in Bellevue and it is likely to have an extensive CMZ in unconfined portions of the drainage. In other smaller streams flowing in ravines or narrow valleys of Bellevue the CMZ may be non-existent. CMZ functions should be considered when developing protective strategies for riparian functions and values.

Providing protection for channel migration zones goes beyond protecting existing habitats and focuses on the processes that create and maintain that habitat. Urban development near streams often leads to a reduction or loss of habitat forming processes associated with the CMZ due to concerns about flood hazards. Where flood control structures, including dikes, levees, or roads are constructed to control the flow of water and reduce flood hazards in an area; spatially these structures decrease the potential habitat quantity and quality formed in the CMZ. Channel migration zones are further discussed in Chapter 3 Frequently Flooded Areas of this report.

5.1.4 Hyporheic Zone

The hyporheic zone lies under the floodplain in a shallow unconfined aquifer that is hydraulically connected with a stream or river. The hyporheic zone typically extends for a considerable distance laterally across the width of the floodplain and many yards beneath the surface of the ground. Aquatic invertebrates depend on the extensive intergravel habitat of the hyproheic zone for refugee during droughts and high-flow events. After such events, invertebrate populations in the hyproheic zone are capable of replenishing the population in an area. Likewise salmonid fish species depend on hyporheic flows for the success and survival during intergravel developmental stages (Baxter and Hauer 2000). Urban development above the hyporheic zone may result in a reduced exchange of dissolved oxygen and nutrients between surface and subsurface waters and between aquatic and terrestrial ecosystems, thereby reducing the functionality of the hyporheic zone for invertebrates (Naiman and Bilby 1998; PSMFC 1999).

In summary the hyporheic zone in urbanized basins within Bellevue are expected to provide surface and ground water interactions influencing water chemistry but more importantly they provide functional habitat for invertebrates (refuge) and developmental habitat for salmon (inter-gravel incubation).

The sustainability and restoration of the habitats and species require protection and restoration of the ecological processes that sustain them in addition to direct protection of the habitat themselves. Without adequate habitat protection, development will cause reductions in the amount and complexity of habitat; increased scouring of the stream channel; reduction or loss of channel migration, sediment supply, and LWD recruitment; and decrease productivity and species diversity (Bolton and Shellberg 2001).

There are a number of strategies for implementing protection and restoration for stream and riparian systems. These include creating a classification system to identify streams and protect riparian ecosystems, establishing buffer zones, designating structures setbacks, and establishing buffers for piped streams.

The following sections provide management strategies based on best available science for protecting the functions and values of streams and riparian systems. The recommendations are strongly influenced by anadromous fish needs. The rationale and other supporting statements are based on previously cited literature in the 2003 streams inventory report and BAS streams paper; however, statements based on new information are referenced by citations.

5.2 Stream Typing System

Stream typing and designation is necessary to protect riparian and stream functions, processes and values. The typing and designation of streams allows for the development of regulations to address processes that are relevant to specific types and sizes of streams. For example, the river continuum concept demonstrates the importance of fishless waterbodies—stream typing will allow for the application of appropriate protections strategies to these areas.

The GMA states that "counties and cities should use the classification system established in WAC 222-16-030 to classify waters of the state." Since the completion of the previous BAS review (Bellevue 2003a), the stream classification used by Washington Department of Natural Resources (DNR) has been modified. DNR in cooperation with the Departments of Fish and Wildlife (WDFW) and Ecology, has prepared a draft map described in and based upon the classification system established in WAC 222-16-030. The new DNR typing system classifies waters by fish, wildlife, and human use, as well as the physical characteristics of the drainage basin (e.g., basin size, gradient, and elevation).

Adoption of the DNR classification system by local jurisdictions is not mandatory—GMA grants counties and cities discretion in the method by which they choose to classify, designate, and protect critical areas, including streams. However, if a county or city opts to use an alternate water classification system, it must show that the system classifies fish habitat. The City of Bellevue presently uses a riparian corridor classification system to identify riparian areas but lacks a traditional stream typing system similar to other local jurisdiction to classify stream types. The present riparian classification system is heavily based on stormwater conveyance and not the elements described in WAC 222-16-030; therefore, the City should consider adopting a new system that recognizes all stream functions or revise its' current system to better reflect the range of stream functions.

5.2.1 Review of the Literature

The DNR water typing system places streams into four major categories: S, F, Np, and Ns. The typing is based on a multi-parameter, field verified geographic information system logistic regression model. The model is habitat-driven and uses geomorphic parameters such as basin size, gradient, elevation, and other indicators to determine the end of fish habitat locations. The modeled end of fish habitat is considered in the waterbody classification rather than the presence or absence of any particular species of fish. Currently DNR is finalizing classifications for individual waterbodies. The following is a summary of the state's type system, based on WAC 222-16-030:

- Type S include waters within ordinary high-water marks, inventoried as "shorelines" of the state under chapter 90.58 RCW but do not include such waters' associated wetlands as defined in chapter 90.58 RCW.

- Type F include all segments of natural waters (other than type S waters) within the bankfull widths of defined channels or within lakes, ponds, or impoundments having a surface area of 0.5 acre or greater at seasonal low water. These waters are described as having fish habitat or by one of the following three categories if it does not contain fish habitat:

- Waters which are diverted for domestic use by more than 10 residential or camping units or by a public accommodation facility licensed to serve more than 10 persons.
- Waters which are within a federal, state, local, or private campground having more than 10 camping units.
- Waters which are diverted for use by federal, state, tribal, or private fish hatcheries.

- Fish habitat means habitat that is used by fish at any life stage at any time of the year including potential habitat likely to be used by fish that could be recovered by restoration or management and includes off-channel habitat. Fish habitat will be established based upon a multi-parameter, field-verified, peer-reviewed GIS logistic regression model using geomorphic parameters such as basin size, gradient, elevation and other indicators.
- Type N include all segments of natural waters other than type S or F waters within the bankfull widths of defined channels and which are either perennial streams or physically connected by an above-ground channel system to downstream waters such that water or sediments initially delivered to such waters will eventually be delivered to a type S or F water.

The state's water typing systems established under WAC 222-16-030 meets the state's best available science requirements (as related to the classification of aquatic habitats) because it is based on fish habitat requirements and it therefore protects habitat for salmonids. Native communities of aquatic organisms also share similar habitat requirements as salmonids (TFW LWAG 1998); therefore protection will be provided for a wide spectrum of aquatic species.

5.2.2 Identification of Data Gaps

The state will not designate stream types within the City of Bellevue. Each stream should be divided into distinct stream segments based on fish habitat. The Stream Inventory Report (Bellevue 2003b) documents streams with salmonid habitat rather than streams with fish habitat. The presence of fish habitat will need to be determined for streams, if the City elects to use the state's classification system.

5.2.3 Recommendations

Consider adopting the typing system adopted by the Washington state legislature for streams and other waterbodies (WAC 222-16-030). The system is based on providing fish habitat and therefore offers protection for ESA listed species. Adoption of the proposed typing system would ensure the appropriate and functional designation of all natural waterbodies within Bellevue. Waterbodies with fish, which are currently designated as type A, B, C, or D riparian corridors, would be separated as either shorelines of the state (type S) or waterbodies with fish habitat (type F). The only stream designated as shorelines of the state within Bellevue is Kelsey Creek east of I-405. The proposed system provides a means to designate type F waterbodies based solely upon physical and geomorphic characteristics (e.g., channel width, gradient, size of contributing basin), which simplifies the designation process for fish habitat. Waterbodies without fish habitat would be designated by flow regime as perennial (type Np) or seasonal (type Ns).

Adoption of the state typing system will ensure consistency with the GMA and subsequently provide protection for ESA listed chinook species.

5.3 Stream Buffers

The terms “buffer” or “stream buffer” are often loosely used as synonyms for riparian areas. However, the term buffer is typically applied in a specific management context to denote an area set aside and managed to protect a natural area from the effects of surrounding land-use or human activities (May 2003; Knutson and Naef 1997). Depending on the context, buffers may be designed to perform a specific function or set of functions, such as filtering pollutants or providing shade (May 2003). The use of the term “stream buffer” in this report and the recommendations therein are directed to protect the area needed for the ecological functions of streams.

Buffer widths associated with a stream are intended to protect an area of sufficient size to provide functions considered important for protecting aquatic processes, riparian species and to buffer against development impacts. Riparian vegetation within stream buffers provide nutrients that sustain the principles of the river continuum concept and the spatial scale of buffer provides lateral space for the channel migration and hyporheic zones.

Stream buffer designation is necessary to protect aquatic area processes and functions. The typing and designation of streams using the stream typing system allows for the development of stream buffer regulations that address functions that are relevant to specific types of streams. For example, the stream typing system separates aquatic areas with fish habitat from those without fish habitat; therefore the stream buffer regulations for fishless areas can be specific to meet the needs of these areas (note: the river continuum concept demonstrates the importance of fishless waterbodies).

A City code outlining requirements for stream buffers is one tool for maintaining the functions, processes and values of streams and salmonid habitat as described in the 2003 Stream Inventory Report and Stream BAS Paper. The 2003 Stream Inventory concluded that riparian areas in the City of Bellevue have been extensively modified due to urbanization. All of the City’s stream basins were rated “high” for the number of riparian breaks indicating that buffer functions are highly compromised due to alterations in the longitudinal integrity or connectivity of the riparian corridor. Riparian breaks can be reduced using regulations or incentives that address the protection, enhancement, and restoration of riparian corridors.

5.3.1 Review of the Literature

The 2003 BAS stream paper provided a review of riparian functions as a factor of buffer width. Table 5-1 is a summary of buffer width requirements from the literature as documented in the BAS stream paper to protect stream and riparian system functions. As indicated in the BAS stream paper, there is no consensus in the literature recommending a single buffer width for a particular function or to accommodate all functions. Knutson and Naef (1997) resolved the variability in the literature by averaging effective buffers widths reported for specific riparian functions. Table 5-2 illustrates the results of the Knutson and Naef (1997) literature review and shows that a buffer width of 147 feet is effective in providing 5 of the 7 riparian functions including: sediment filtration, erosion control, pollutant removal, LWD, and water temperature protection.

Table 5-1. Riparian buffer functions and appropriate widths identified by May (2003).

Riparian Function	Range of Effective Buffer Widths (feet)	Minimum Recommended Widths (feet)	Notes on Function
Sediment Removal/Erosion Control	26 – 600	98	For 80% sediment removal
Pollutant Removal	13 – 860	98	For 80% nutrient removal
LWD Recruitment	33 – 328	164	1 SPTH based on long-term natural levels
Water Temperature	36 – 141	98	Based on adequate shade
Wildlife Habitat	36 – 141	328	Coverage not inclusive
Microclimate	148 – 656	328	Optimum long-term support

Table 5-2. Riparian functions and appropriate widths identified by Knutson and Naef (1997).

Function	Range of Effective Buffer Widths (feet)	Average of Reported Widths (feet)
Sediment filtration	26 – 300	138
Erosion Control	100 – 125	112
Pollutant Removal	13 – 600	78
LWD Recruitment	100 – 200	147
Water Temperature Protection	35 – 151	90
Wildlife Habitat	25 – 984	287
Microclimate	200 – 525	412

5.3.1.1 Site Potential Tree Height Concept (SPTH)

Much of the work regarding adequate riparian buffer widths has been based on site-potential tree height, defined as the height that mature trees in a climax forest will reach given local conditions (Sedell et al. 1996; Pollock and Kennard 1998). SPTH is considered the maximum horizontal distance from which LWD will be recruited to the stream by falling trees.

The Federal Ecosystem Management Team (FEMAT) while assessing riparian protection strategies for national forest lands first proposed the STPH concept. FEMAT reasoned that tree height is a good scaling factor for buffers because they are a dominant factor determining habitat conditions and their heights reflect inherent productivity and constraints of a site when left unmanaged. FEMAT documents that when buffer widths equivalent to one SPTH are established, a variety of ecological functions are protected including shade, litter fall, root strength and a potential LWD recruitment. Additionally, FEMAT proposed that a buffer width equivalent to three SPTH would fully protect microclimate functions (soil moisture, radiation, soil temperature, air temperature, wind speed, and relative humidity).

The actual height that a dominate tree would grow at a site depends on the species, soils, climate, and disturbance history of a site (Sedell et al. 1993). Pollock and Kennard (1998) provide that SPTH for Douglas fir ranges from 198 to 218 feet for two riparian plant association groups on the Mount Baker-Snoqualmie National Forest. SPTH data are not readily available for other trees, such as western red cedar, or sitka spruce, which can be as tall or taller than Douglas fir, depending on site conditions, or for black cottonwood, red alder and bigleaf maple, which are smaller in maximum height and therefore would likely have smaller SPTH values than for Douglas fir. There is a lack of mature trees along most streams within Bellevue; and little information on dominant riparian vegetation or species diversity; however, there is a mixture of deciduous and coniferous forest occurring along some streams within Bellevue (Bellevue 2003b).

Soil surveys conducted by the U.S. Department of Agriculture, Natural Resource Conservation Service (NRCS), provide site indexes for tree height. Site indexes are based on certain tree ages and the local soil characteristics. The information provided by NRCS is limited to growth achieved in 50 or 100 years and thus do not represent a true SPTH for longer lived species such as Douglas fir. The dominant soils within Bellevue are Alderwood soils (Bellevue 2003c). NRCS reports a site index of 146 feet for a 100-year-old Douglas-fir growing on Alderwood soils (USDA 1973). A tree height of 146 feet is equal to roughly 67 to 74 percent of the SPTH provided by Pollock and Kennard for mature forest. The literature supports that 100 years provides adequate time for the growth of a tree to a size which is capable of functioning as LWD (Franklin and Thomas 1983; Montgomery et al. 2003). Furthermore, studies have shown that more than half of all large woody debris is recruited from within 15 feet of streams, and about 90 percent comes from trees growing within about 50 feet of streams (McDade et al.1990; Van Sickle and Gregory 1990). Therefore, the growth of a tree at 100 years at a distance of 146 feet perpendicular to a stream channel is adequate for LWD recruitment within Bellevue's streams.

Table 5-3 is a summary of buffer width requirements in terms of SPTH to protect ecological functions. Generally speaking a buffer width roughly equal to one SPTH will provide the ecological functions necessary to support salmonids and most stream ecosystems; the exception to one SPTH distance is wildlife habitat and microclimate processes which may need much larger areas. As stated previously soil maps for the Bellevue area indicate that a 100-year-old Douglas fir tree would be 146 feet. Using 147 feet as a standard buffer width for streams would be consistent with buffer width requirements for riparian functions identified by Knutson and Naef (sediment filtration, erosion control, pollutant removal, LWD recruitment and temperature regulation – see Table 5-2) and buffer width requirements identified using the SPTH concept.

Table 5-3. Riparian function and appropriate widths identified from FEMAT (1993).

Function	Number of SPTH	Equivalent Based on SPTH of 200 (feet)
Shade	0.75	150
Microclimate	Up to 3	Up to 600
LWD Recruitment	1.0	200
Organic Litter	0.5	100
Sediment Control	1.0	200
Bank Stabilization	0.5	100
Wildlife Habitat	0.5 to 3.0	98-600

5.3.1.2 Three- and Two-Zone Buffer Width Approach

Besides using a single fixed buffer width prescription tailored after the SPTH concept there are other options for protecting streams using buffers. The Three-Zone Buffer Concept provides a framework for thinking about the establishment and maintenance of long-term stream buffers. Zone 1 is adjacent to the water's edge and Zone 3 is the outermost area from the stream. The important function of Zone 1 is to protect the physical integrity of the stream ecosystem; acceptable uses in Zone 1 include flood control, utility right of way and footpaths. Zone 2 is designed to provide distance between upland development and the innermost zone; Zone 2 is for uses such as outdoor recreation, bike paths and wildlife habitat. The outer zone or Zone 3 prevents encroachment and filters surface water runoff; allowable uses in Zone 3 include unrestrictive residential uses such as lawn, gardening and compost piles (Stormwater Center 2004) but excluding structures. All three zones provide wildlife habitat.

The 2003 BAS Stream Paper discussed the Two-Zone Buffer Concept and used the Snohomish County system as an example. The Snohomish buffer system separates the traditional buffer zone into two areas, an inner "no touch" zone and an outer "management zone." The Snohomish County system recognizes that the land directly adjacent to streams has the potential to offer higher levels of functions and values than areas farther from the stream. This method reflects, in large part, the findings of literature reviews that show many of the critical functions of riparian areas occur in those areas directly adjacent to streams and that the ability of the buffer to provide beneficial functions and values plateaus at a given distance (relative to the function that is the focus of the investigation). Under the Snohomish County system, the interior one-half of the regulated area, known as the "buffer," is managed to allow very limited disturbance. A higher level of alteration or use is allowed in the outer one-half of the regulated area, known as the "management zone," but more intensive development is still discouraged.

In summary, riparian areas (native vegetation adjacent to streams) provide numerous ecological functions and resource management benefits. Establishing buffers adjacent to streams is one way to protect and maintain riparian area functions and benefits. The ability of a buffer to provide multiple functions and benefits is closely linked to its width but other factors such as slope, vegetation, soil type, buffer design, and buffer management also determine its effectiveness. Riparian forest studies discussed in this report correlate buffer widths to riparian functions. Tables 5-1, 5-2, and 5-3 summarize relevant literature by providing a range of buffer widths for achieving each riparian function.

A vegetated stream buffers established using the SPTH concept can adequately provide the ecological functions necessary to support salmonids and most aquatic area processes. Aquatic area processes such as nutrients from the river continuum and natural disturbances such as flooding will continue to function along small streams protected with buffer widths established using the SPTH concept. Because much of the riparian forests in Bellevue are significantly modified it is necessary to reference the historical conditions of forests to determine the height of mature dominant tree species under normal local growing conditions.

5.3.2 Identification of Data Gaps

The majority of scientific studies that critically examine the functions and values associated with stream buffers have been conducted in forested environments. As such, fundamental differences between forested and urban areas, including land use (zoning) and hydrology (stormwater conveyance systems), are not considered. Moreover, there is a lack of literature concerning the scientific basis for using riparian buffers as landscape structures in maintaining landscape-level processes such as natural disturbances within urban areas.

5.3.3 Recommendations

Establishing buffers adjacent to streams is one way to protect and maintain riparian areas and thereby the functions and values they provide. Based on the literature review, adequate buffers can be established using the SPTH concept, which is consist with the literature review and other best available science reviews by local jurisdictions. For example, a buffer width of 147 feet on each side of a stream is effective in providing sediment filtration, erosion control, pollutant removal, LWD recruitment, and water temperature protection is (May 2003). Similarly, a buffer width equivalent to one SPTH provides a variety of riparian ecological functions including shade, litter fall, root strength (stabilizes streambanks), and potential for LWD recruitment. The height of a site potential tree for a mature Douglas-fir tree for the types of soils found within the City of Bellevue is 146 feet. Both 147 feet and 146 feet are within the range of recommended buffers for shade, water temperature, erosion control, removal of sediment and pollution, and LWD recruitment. Three times the height of a site-potential tree (438 feet) would provide effective wildlife habitat and microclimate functions.

Narrower buffers can provide some ecological functions. A 100-foot buffer vegetated with native plant species would provide approximately 80 percent of sediment and pollutant removal functions but inadequate LWD recruitment potential (see Table 5-1). In general, larger buffer widths provide greater environmental protection and resource management benefits. The City should consider what functions are desired of buffers and choose a buffer width requirement that would provide those benefits. Based on the river continuum and natural disturbance concepts, important ecological function occur along small streams protected with buffer widths established using the SPTH approach. Therefore, the selected buffer width should be applied to all waterbody types regardless of whether fish species are present.

In general, a buffer width meeting the SPTH concept will provide the ecological functions necessary to support salmonids and most aquatic area processes; however, additional protective regulations to protect the functions of the stream buffer are discussed in a section on setbacks which follows.

Stream buffers should be measured from the CMZ if one is present. If a CMZ is not present, the measurement should be made from the ordinary high water mark (OHWM). The CMZ is an area where natural riverine processes are allowed to distribute sediment, recruit woody debris, and provide high quality habitat for salmonids and other wildlife. Vegetation management in the CMZ should be regulated consistent with DNR Forest and Fish Rules. The Forest and Fish Rules [222-30-020(12) WAC)] have been determined by NOAA Fisheries to be consistent with the best available science for protection of endangered species (NOAA Fisheries 2003).

Within the City continuous buffers are not possible in most areas due to existing development. Alternatively, buffer width designs may allow for averaging buffer widths to improve the protection of functions and values of streams. No scientific information is available to determine if averaging widths of buffers actually protects stream functions. In general buffer averaging should only be considered under the following three conditions:

1. The total area of the buffer after averaging is equal to the area required without averaging;

2. Low intensity land uses will be adjacent to the reduced buffer widths;

3. Stream functions and/or values will not be adversely impacted.

Furthermore, if buffer averaging is permitted, buffers should still include the structure setbacks recommended in the following section.

5.4 Setbacks

Structure setbacks provide protection to aquatic area processes and riparian functions and values by increasing the distance between human activities and the stream buffers which protect riparian functions. Stream buffers sustain riparian functions and stream processes while the structural setbacks protect stream buffers from urban encroachment. The recommended stream buffer widths in the previous section will provide for adequate riparian functions along Bellevue’s streams; however, this adequacy is closely linked to absence of active urban encroachment adjacent to and within the stream buffer. Structure setbacks are areas adjacent to stream buffers where buildings and other facilities are not constructed; however, these areas may allow low impact activities such as gardening and lawns.

5.4.1 Review of the Literature

As stated in the previous section buffers are areas set aside and managed to protect a natural area from the effects of surrounding land-use or human activities (May 2003; Knutson and Naef 1997). The scientific literature supports the maintenance of stream buffers as restricted-use zones to provided ecological functions necessary to support salmonids and most aquatic area processes (Knutson and Naef 1997).

Encroachment of human land-use activities into the stream-riparian ecosystem has the potential to degrade the structural and functional integrity of aquatic systems (May 2003). Land uses adjacent to stream buffers such as residential development or commercial development may degrade the quality of riparian functions due to light, noise and human intrusion (Leavitt 1998). The degree of these disturbances within the riparian area may preclude some of its ecological functions. Higher intensity land uses, such as high-density residential development or commercial development, located adjacent to stream buffers could result in greater impacts than lower density single-family residential uses (Leavitt 1998). As the degree of disturbance increases, the loss of functions increases (e.g., loss of LWD recruitment; Christensen et al. 1996). Hence, a structure setback is needed in order to prevent disturbance of the riparian functions occurring within the stream buffer.

A structure setback in conjunction with a stream buffer is recommended in the literature in order to limit disturbance to riparian functions that occur within the buffer. The most often recommended structure setback to buffers is an additional 25 feet (Illinois Environmental Protection Agency 1996). May (2003) recommends that “the type and intensity of the surrounding land-use determine the additional [protective buffer] width required to protect the [stream buffer]”. Land uses that present greater risk of damage to aquatic ecosystem include high-density residential, commercial, or industrial; May (2003) states that these areas merit larger structure setbacks.

5.4.2 Identification of Data Gaps

The characterization of land uses adjacent to streams was not reported in the 2003 stream inventory report. This information is needed in order to merit additional protection to specific segments of streams which present greater risk of damage to stream functions and values.

5.4.3 Recommendations

A structure setback to stream buffers can prevent disturbance of the riparian functions that are integral to stream. A structure setback of 25 feet to the stream buffer is the most commonly recommended setback in the literature (Illinois Environmental Protection Agency 1996). Structure setbacks are recommended along all water types within Bellevue due to the extensive degradation of all its riparian areas.

5.5 Piped Stream Buffers

In the City of Bellevue, streams segments have been placed in pipes to accommodate development. Piped stream segments limit available habitat, can inhibit fish movement, migration, and prohibit fish from accessing upstream habitats. Piped stream segments that do not prevent fish migration may still limit many aquatic area processes necessary for salmonid fish production including riparian functions (Bellevue 2003a) and aquatic area processes.

Establishing buffers adjacent to piped streams is a means of preserving space and, when available, natural forest conditions for future opportunities to daylight piped stream segments and return streams to surface flows. Although much of Bellevue is built out and piped streams segments are typically located in paved areas, planning for buffers on piped stream segments will allow for future stream restoration opportunities while providing adequate buffer protection. Restoring piped streams to a more natural condition by opening segments and providing stream buffers may improve overall watershed conditions for aquatic resources by reestablishing aquatic area processes and functions. Some of the potential benefits of restoring streams to surface flows include improvements to the functional values of waterways and urban stormwater systems through increased hydraulic capacity for flood control, lowering of water velocities to reduce downstream erosion, and removal of water from combined sewers thereby improving water quality. Additionally restoring piped stream segments can reestablish the processes sustained by interactions between streams and adjacent riparian areas in which salmonids and other aquatic resources rely on such as regulating temperatures, sources of LWD, and aquatic areas processes described in this report (i.e., natural disturbance, river continuum concept, hyporheic zone and channel migration zones).

5.5.1 Review of the Literature

A review of projects that restored buried streams to surface flows provides a framework to examine buffer widths for piped streams. Pinkham (2000) summarized a range of projects that reestablished surface flows to buried stream channels. The primary technical elements to consider when restoring a channel to the surface are channel design and floodplain. Whether the channel meanders and if it has an associated floodplain will determine what buffer widths around a piped stream would be adequate for restoring the stream to a surface flow. Consideration should also be given to the potential for CMZ and buffer width requirements. This will ensure that all necessary ecological functions are provided, once the stream piped segment is restored.

5.5.2 Identification of Data Gaps

The locations of piped stream segments are not plotted against current land uses within Bellevue. This information will be needed to evaluate potential environmental benefits of daylighting streams and would provide rationale to support establishing set aside buffers for future projects to restore piped stream segments. The scientific literature does not provide a recommendation for buffers adjacent to piped streams.

5.5.3 Recommendations

There is no scientific justification for establishing buffers adjacent to piped streams to maintain current functions. Establishing piped stream buffers is a matter of preserving future restoration opportunities. Restoring fish passage by daylighting stream segments is an effective way to increase the quality and accessibility of habitat and can result in relatively large increases in potential fish production at a nominal cost (Roni et al. 2002). If the City would like to establish stream buffers to protect piped streams that will be daylighted in the future, the buffer width can be based on the SPTH concept. A structure setback of 25 feet from the buffer of daylighted stream segments would be adequate.

5.6 Stewardship Program

Stream buffers and structure setbacks separate streams from uplands and surrounding development, protecting streams from human encroachment. The purpose of a stewardship program is to provide opportunities to establish or mitigate stream buffer widths in areas where is it not possible. A stewardship program can include incentives that improve the conditions of degraded stream buffer and streams functions and values.

Site-specific conditions or land-use constraints may necessitate that a reduced stream buffer be designated along streams. For example, a stream may flow through an already developed area, with roads, homes, and other structures currently limiting the extent of the riparian corridor. In these cases, riparian quality may be degraded significantly. Riparian areas along Bellevue's streams are extensively modified due to urbanization and all of the streams rate high for the number of riparian breaks (Bellevue 2003b). Stream buffers and structure setbacks may not be effective in some of these areas.

5.6.1 Review of the Literature

The analysis of buffer width functions in the literature are based on areas vegetated with native plant communities (Table 5-1). Sparsely vegetated or vegetated buffers with non-native species may not perform the needed functions of stream buffers. In cases where the buffer is not well vegetated, it is necessary to either increase the buffer width or require that the standard buffer width be revegetated (May 2003). Until the newly planted buffer is established the near term goals for buffer functions may not be attained. Newly established buffers do not provide desired riparian buffer functions such as species migration, sediment filtration, or nutrient and woody debris inputs (Knutson and Naef 1997).

One of the greatest impacts of urbanization on wildlife species comes from riparian breaks and habitat fragmentation (May 2003; Stenberg et al. 1997). The concept of metapopulation contributes to an understanding of how isolated remnant habitat parcels make utilization and recolonization difficult or impossible for wildlife species. Habitat fragmentation that prevents the source and sink dynamics of the metapopulation concept to occur may result in permanent loss of populations due to the lack of connectivity. This is of particular concern for species with low mobility such as amphibians (Richter 1995). The restoration of degraded areas to habitat used by fish and wildlife is needed to rebuild healthy fish and wildlife populations.

Instream restoration projects should be planned carefully in the context of basin-wide conditions. In one study of 15 streams in Oregon and Washington, more than half of instream LWD restoration structures failed before the expected lifetime of 20 years (Frissell and Nawa in McClean 2000). Roni et al. (2002) reported highly variable results; some studies suggested that 85 percent of wood remains in place and contributes to habitat formation. Often in urban systems, more engineered methods of bed and bank stabilization may be necessary to address high hydraulic forces, space constraints, and infrastructure and property protection restrictions (Miller et al. 2001).

5.6.2 Identification of Data Gaps

The City of Bellevue will need to examine locations in basins where a restoration program would be appropriate and select locations and activities so that restoration efforts match conditions downstream.

5.6.3 Recommendations

Landowners should be educated on the importance of protecting and maintaining stream buffers and encouraged to take an active role in stewardship. Instream channel restoration in addition to riparian restoration may improve the functions and values of streams. Restoration opportunities are identified in the following section.

5.7 Additional Approaches to Protecting Salmonids

Best available science of what constitutes salmonid habitat is still evolving. It is currently shifting from site-specific structures and ecological functions to aquatic area and landscape-scale processes (e.g., natural disturbances, hyporheic zones, and core populations) that shape and maintain salmonid habitat and populations. These changes in what we consider stream habitat and how salmonids use that habitat are important to consider when developing policies. The simple application of prescriptive buffers may not be adequate to restore urban streams because most of the source functions of buffers have been compromised by past land use actions

(Bellevue 2003a). Additionally, along most urban streams it will be difficult to restore LWD recruitment due to the difficulties in restoring mature forests. Actions will need to occur that maintain or restore ecological processes, functions, and the natural disturbance regimes along streams.

Management and restoration of habitat must also consider the whole watershed and ecological processes for salmonids to complete their life histories. It may be necessary to develop new watershed-based strategies that address hydrology, water quality, and riparian functions to successfully address the issue of riparian areas and adequate buffers in the context of basin-wide change. Some restoration opportunities to improve Bellevue's streams include:

- Designing and installing LWD to provide hydraulic refuge areas during peak flows in Lakehurst, Yarrow, South Sammamish, and Lewis Creek.
- Planting native coniferous trees in the riparian areas along all of Bellevue's streams. The first priority should be the mainstem of Kelsey Creek.
- Reducing invasive non-native plants along stream reaches with salmonids use.
- Modifying existing culverts that are partial barriers by placing low-flow deflectors on multi-channel box culverts to increase depth of low-flow channel.
- Replacing culverts that are barriers to fish passage.
- Restoring and enhancing degraded wetlands to restore off-channel and riparian wetland habitats along stream segments.

Furthermore, the City of Bellevue may consider identifying projects that would allow unimpeded access to all potential natural spawning and rearing habitats for all life stages of the Kelsey Creek satellite chinook salmon population. Specific action alternatives to restore and protect fish habitat for the Kelsey Creek population are outlined by the Lake Washington, Cedar, and Sammamish Watershed Steering Committee (WRIA 8 Steering Committee 2002).

5.8 Conclusion

This summary of the best available science for developing policies and regulations to protect the functions and values of stream and associated riparian areas is based on peer-reviewed research; Bellevue's 2003 *Critical Areas Update, Stream Inventory Report;* Bellevue's 2003 *Critical Areas Update, Best Available Science Paper: Streams*; symposia literature; technical literature; and other scientific information related to streams. The review focused on recommended conservation or protection measures to preserve or enhance anadromous fish species and habitat that is important for all life stages of anadromous fish. Best available science for stream and riparian protection, particularly safeguarding the processes that protect riparian functions, varies in terms of quantity, quality, and local relevance. The best available science for stream and riparian protection is neither complete nor consistently covers all functions, and it remains an active field of research. Table 5-4 summarizes the best available science positions on stream and riparian area protection and provides general recommendations for the City of Bellevue.

Human development of land and water typically affects stream functions and processes in profound ways, ultimately affecting the type and abundance of existing species. Sustaining natural functions and processes is essential to maintaining stream habitats and the species that rely on them. Streams are formed and sustained by many important physical and biological processes which include but are not limited to:

- Natural disturbances
- Hyporheic zone interactions
- Habitat-forming processes
- Stream/riparian interactions within the channel migration zone.

Natural disturbances sustain species diversity and create habitat. The hyporheic zone provides surface and ground water interactions, influencing water chemistry, sustaining refuge habitat for invertebrates, and providing developmental habitat for salmon. The channel migration zone allows for habitat creation and sustainability by providing lateral areas for streams to migrate across the floodplain (see Figure 5-1). Because of the unique mix of water and biodiversity, stream and riparian areas are used by a broad range of species including by humans for recreational and aesthetic activities, fishing, and the enjoyment of natural beauty and solitude.

The sustainability and restoration of habitats and species requires the protection and restoration of the ecological functions and processes that sustain them, in addition to the direct protection of the habitats themselves. Without adequate habitat protection, development will produce the following conditions in streams and riparian areas:

- Reductions in the amount and complexity of habitat
- Increased scouring of stream channels
- Reduction or loss of channel migration, sediment supply, and the recruitment of large woody debris
- Decreased productivity and species diversity.

Water body typing and designation are necessary for protecting stream and riparian functions, processes, and values. The classification of water bodies allows for the development of regulations to address functions and processes that are relevant to specific types of water bodies. The Growth Management Act (Section 5.c.vi of WAC 365-190-080 Critical Areas (vi) Waters of the state) states that counties and cities should use the classification system established in Washington Administrative Code, Chapter 222-16, Section 030 (WAC 222-16-030) to classify

Table 5-4. Summary of best available science findings and general recommendations for protecting streams.

Protection Mechanism	Best Available Science Review	General Recommendations
Adopt a stream typing system to address processes that are relevant to specific types of streams and fish habitat.	The DNR water typing system considers fish habitat rather than presence or absence of fish species.	Adopt the DNR stream typing system.
Implement riparian structure setbacks which protect an area of sufficient size to provide riparian and aquatic processes and functions, protect riparian species, and buffer against development impacts.	The effectiveness of a buffer to provide multiple functions and benefits is linked to its width and other facts such as slope, vegetation characteristics, soil type, buffer design and buffer management. Many of the critical functions of riparian areas occur in those areas directly adjacent to streams and plateaus at a given distance. Buffer width established using the site potential tree height (SPTH) concept can provide the ecological functions necessary to support salmonids and most riparian and aquatic functions and processes.	The developed character of the City makes adoption of fully protective buffers impractical therefore adoption of buffers that provide the greatest riparian functionality is advised. Measure riparian structure setbacks from the channel migration zone or ordinary high water mark.
Provide stewardship programs as incentives to restore and protect riparian functions where stream buffers are not possible.	Processes and functions provided in the literature for buffers are based on areas vegetated with native plant species at densities of native plant communities. Sparsely vegetated or vegetated buffers with non-native species may not perform the needed functions of stream buffers.	Educate landowners on the importance of protecting and maintaining stream buffers. The City should provide partnerships with landowners for riparian restoration projects.
Increase the distance between human activities and stream buffers.	High-density residential, commercial, and industrial land-uses often necessitate wider structure setbacks from aquatic ecosystems to better protect streams from the higher levels of disturbances associated with more intensive land uses.	A 25-foot structural setback to stream buffers along all water types is preferred when possible to prevent disturbance of riparian functions.
Restore fish habitat and passage by daylighting stream segments.	The primary technical elements to consider when restoring a channel to the surface are channel design and floodplain.	Establish piped stream buffers based on buffer widths meeting the SPTH concept and, when possible include a 25-foot structural setback. The preserved land area will provide space for daylighting a stream segment. The developed character of the City may preclude this protective mechanism in many areas.
Implement restoration and enhancement strategies to improve or prevent additional degradation of riparian habitat.	Watershed-based strategies that address hydrology, water quality, and riparian functions are the most successful in addressing riparian areas and adequate buffers in the context of basin-wide change.	Restore degraded riparian areas using strategies which emphasize the whole watershed and ecological processes which include the following: ▪ Design and install LWD ▪ Plant native coniferous trees along streams ▪ Reduce invasive non-native plants along streams ▪ Replace or modify culverts which prevent fish passage ▪ Restore and enhance wetlands to restore off-channel habitat.

waters of the state. Waters of the state are defined in Title 222 WAC, the forest practices rules and regulations. Counties and cities are expected to use the classification system established in WAC 222-16-030 to classify waters of the state. WAC 222-16-030 outlines the state's classification for water bodies into three categories: Type S waters (shorelines of the state), Type F waters (fish habitat), and Type N waters (nonfish habitat). The current Bellevue riparian corridor classification (Type A-D) does not readily align with the proposed state system.

Should the City of Bellevue adopt the classification system for streams and other water bodies established by WAC 222-16-030, it will ensure consistency with the Growth Management Act and the permit requirements of state agencies. Adoption of the state's classification system will also protect the chinook salmon, a species that is protected under the Endangered Species Act because under the recommended stream typing system, stream segments classified as Type S or Type F waters could receive additional stream buffer protection.

Stream buffers are necessary to protect the functions and processes of riparian and aquatic areas. Current scientific research indicates that stream buffer requirements are best established using the site-potential tree height concept (SPTH). The height of a site potential tree for a mature Douglas-fir tree for the types of soils found within the City of Bellevue is 146 feet. A similar size buffer width of 147 feet on each side of a stream is identified in the literature as effective in providing sediment filtration, erosion control, pollutant removal, LWD recruitment, and water temperature protection. Smaller buffers may protect some level of functional effectiveness but would not be expected to fully protect stream and riparian area functions.

The stream buffer should be a "no-touch zone" in which minimal activities occur so that the ecological functions of the stream are protected. A structure setback of 25 feet is preferred, whenever possible in addition to the stream buffer to act as a regulated transition area. The structure setback should be measured from the edge of the buffer.

Buffers are also recommended for segments of piped streams in Bellevue, particularly when they are fish bearing. Piped stream segments limit available habitat, can inhibit resident fish movement and anadromous fish migration, and prevent fish from accessing upstream habitats. Piped stream segments that do not prevent fish migration may limit many aquatic processes necessary for salmonid fish production. Establishing buffers adjacent to piped streams is a means of preserving space and, when available, natural forest conditions that will allow for future opportunities to restore piped stream segments to surface-flowing streams. Although much of Bellevue is built out and piped stream segments typically are located in paved areas, planning for buffers on piped stream segments will allow for future stream restoration opportunities while providing adequate buffer protection. The stream buffer for piped stream segments can be based on a buffer width meeting the SPTH concept in addition to a structure setback of 25 feet in areas where possible.

Stewardship programs are recommended non-regulatory measures to assist in the protection and restoration of functions and values of streams and associated riparian areas. Stewardship programs often provide incentives that encourage property owners to improve degraded stream buffers and instream habitat. Examples of rehabilitation activities sponsored by a stewardship program may include matching grants to remove invasive nonnative plant species and reestablishing stream buffers with native coniferous trees.

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